Precision Electroweak Constraints and the Mixed Radion-Higgs Sector[*]

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Abstract

Adding radion perturbations (up to second order) to the static (RS) metric allows us to calculate the general first and second order interactions of the radion field with the electroweak vector bosons. We use these interactions to compute precision electroweak observables in the case of Higgs-radion mixing and compare with experiment.

1 Introduction

An interesting Brane World Scenario proposed by Randall and Sundrum (RS)[1] involves one extra dimension with warped geometry. This warping can account for the hierarchy between the weak scale and the Planck scale. In this framework the corrections to precision electroweak observables can be described by the Peskin-Takeuchi parameters S and T, and can come both from the Higgs-radion sector[2, 3, 4] and from the Kaluza Klein excitation sector[5]. Here we would like to refine and expand upon precision electroweak constraints on the Higgs-radion sector[6], focusing on those regions of parameter space for which the KK excitations are too massive to have significant S and T contributions.

Ignoring tensor perturbations, the metric of the five-dimensional space can be written up to quadratic terms in the radion $r(x)$ as

$$
\begin{aligned}
ds^2 &= \left[e^{-2\sigma}\eta_{\mu\nu} - \hat{\kappa}\left\{\eta_{\mu\nu}\, c(y)r(x)\right\} - \hat{\kappa}^2\eta_{\mu\nu}e^{2\sigma}a(y)r^2(x) \right] dx^\mu dx^\nu \\
&\quad + \left[1 + \hat{\kappa}2e^{2\sigma}e(y)r(x) + \hat{\kappa}^2 e^{4\sigma}f(y)r^2(x) \right] dy^2
\end{aligned}
\tag{1}
$$

where $\hat{\kappa}^2 = M_{\mathrm{Pl}_5}^{-3}$ and $r(x)$ is the non-canonically normalized radion field. In the unphysical case of no radion stabilization (i.e., no radion mass) $\sigma(y) = ky$ (in the bulk), $c(y) = e(y) = 1$, $a(y) = 1/4$ and $f(y) = 2$ (no $r\partial_\mu r\partial^\mu r$ trilinear self

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interactions in this limit). We assume that all the Standard Model particles live on the "SM brane" at $y = y_0$. On the other hand, the graviton wave function is peaked at the "Planck brane" at $y = 0$.

The interactions of the canonically normalized radion ϕ_0 with the SM vectors, up to order ϕ_0^2, are

$$L_{int}(\hat{\kappa}^1) = -\left(\frac{1}{\Lambda_\phi}\right) \phi_0 \left[M_V^2 V^\alpha V_\alpha - \epsilon \, L_V\right] \tag{2}$$

$$L_{int}(\hat{\kappa}^2) = \frac{4}{\Lambda_\phi^2} \phi_0^2 \left[\frac{\eta}{2} M_V^2 V^\alpha V_\alpha - \epsilon \left(\frac{(2\eta - 1)}{4} L_V + \frac{1}{4} M_V^2 V^\alpha V_\alpha\right)\right] \tag{3}$$

where L_V is the usual Lagrangian density of a massive vector field. Λ_ϕ sets the strength of these interactions, and should be of order $\simeq 1$ TeV. We have also defined $\eta = a(y_0)/c(y_0)^2$ which should be of order unity. The ϵ in the above equations is a remnant of the dimensional regularization requirement of working in $D = 4 - \epsilon$ dimensions.

There may exist a Higgs-radion mixing[7] term $L = \xi \partial h_0 \partial \phi_0$ derived from the SM-brane operator

$$L = \xi \int d^4x \sqrt{g_{\rm ind}} R(g_{\rm ind}) H^\dagger H. \tag{4}$$

The mass eigenstates h and ϕ can be obtained from the "geometry eigenstates" h_0 and ϕ_0 by suitable field redefinitions[2, 8]. The interactions between these new physical fields and the electroweak vector bosons will be altered by this mixing.

2   Precision electroweak constraints

We can now compute the S and T parameters, both of which have several types of contributions. First, we have direct contributions of each eigenstate of the Higgs-radion system. There are also contributions from the so-called "anomalous terms" coming from the ϵ terms in (2) and (3). Finally, we also expect non-renormalizable operators to contribute. Naively one could expect these operators to be suppressed by powers of M_{Pl}^{-1}. However as a consequence of the warped geometry, the actual suppression is by powers of Λ_ϕ^{-1}[†].

As shown in Fig. 1, when the physical eigenstate masses m_h and m_ϕ are both relatively modest in size, precision electroweak constraints disfavor[‡] the large-$|\xi|$ wings of the theoretically allowed hourglass-shaped region in the (ξ, m_ϕ) plane. The dependance on the parameter η is minimal.

[†]To account for these effects, we basically follow Ref[2]

[‡]In order to determine the allowed regions of S, T parameter space, we have employed a χ^2 ellipse parameterization.
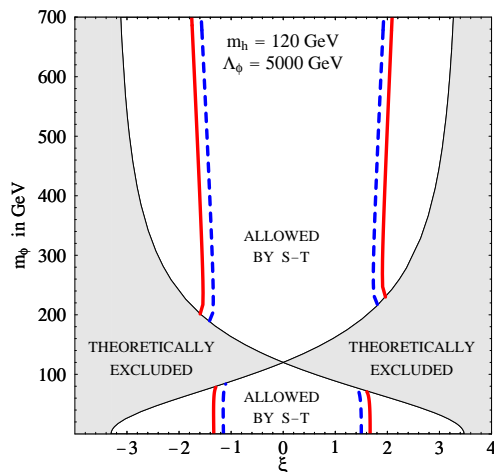
Figure 1: Allowed and disallowed regions in (ξ, m_ϕ) parameter space, assuming $\Lambda_\phi = 5$ TeV, $m_h = 120$ GeV and $\eta = 1/4$. Regions within the theoretically allowed hourglass shape that are excluded at the 68% and 90% confidence level are those with $|\xi|$ values larger than given by the thick dashed (blue) and solid (red) curves, respectively.

We now consider large scalar masses, and large values of the mixing parameter ξ. In Fig. 2, we fix $m_h = 350$ GeV, $\xi = -2$ (left) and $m_h = 650$ GeV, $\xi = -4$ (right), and show 90% confidence level contours of allowed regions and disallowed regions in the m_ϕ-Λ_ϕ plane.

The lightly shaded tower in this figure is "theoretically excluded" because it is impossible for both mass eigenstates to exist for the particular set of input values (one of the fields becomes a ghost). The darker (red) shaded regions are allowed by precision electroweak data. These regions are characterized by Λ_ϕ near the theoretically allowed minimum value and m_ϕ somewhat near the Higgs mass. We see that an extraordinarily heavy radion mass compared to the Higgs mass is too disruptive to the S-T fits.

When increasing the Higgs mass with fixed ξ, the large m_ϕ allowed region tends to disappear. But, as shown in the right panel of Fig. 2 we recover a region compatible with precision electroweak data constraints with a larger value of $|\xi|$. Results for $\xi > 0$ are similar in nature.

Varying the parameter η changes somewhat the form of the allowed regions[§], but this does not affect the general conclusion that a heavy Higgs boson mass and a heavy radion can both be above the putative Higgs mass upper limit from precision electroweak data.

[§]See [6] and references therein for a more complete analysis and collider impact.
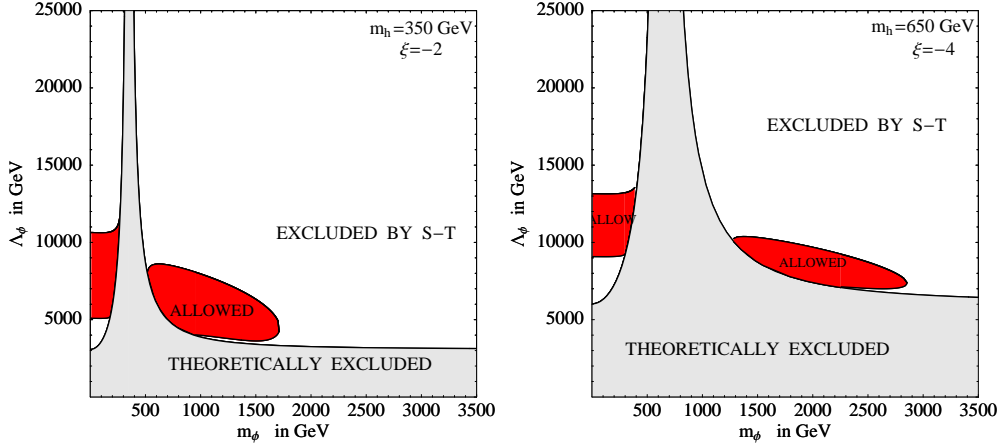
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Figure 2: Precision electroweak allowed and disallowed regions (at 90% CL) of the radion mass as a function of Λ_ϕ, whith fixed values of m_h and ξ. In both panels $\eta = 1/4$.

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